Dealing with arsenic problems of northeastern Wisconsin

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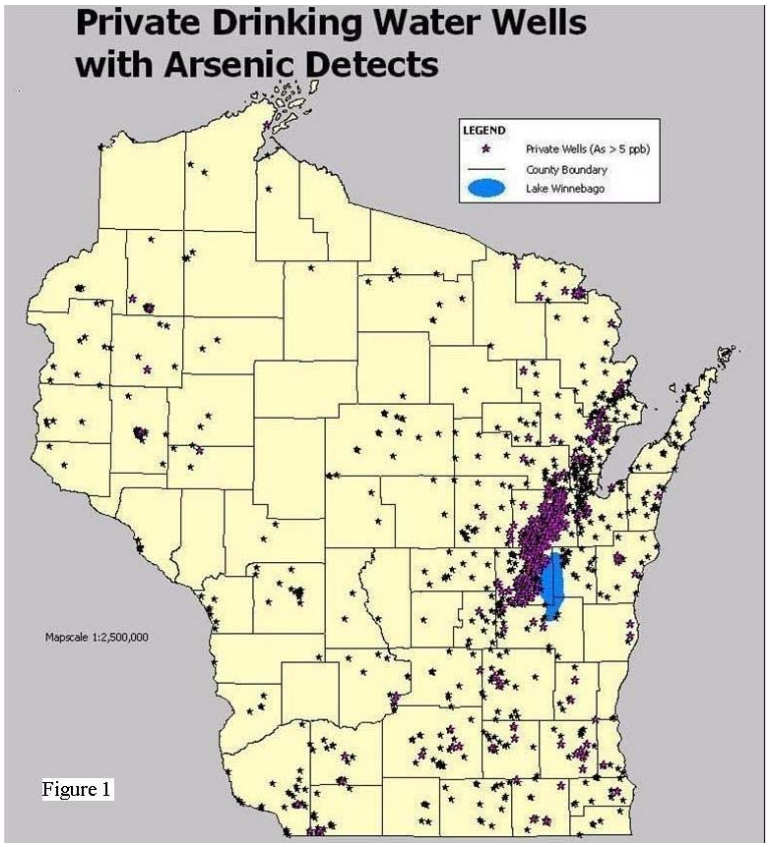
Arsenic contamination in northeastern Wisconsin has prompted the Department of Natural Resources (DNR) to establish a "Special Well Casing Depth Area" (SWCDA) for all of Outagamie and Winnebago Counties. The more stringent construction specifications for this area have been effect since October, 2004.

Arsenic has been a concern in this region of Wisconsin ever since elevated levels showed up in groundwater samples collected by DNR staff in the late 1980s. In 2001, due to convincing data relating to health effects of arsenic ingestion, U.S. EPA lowered the arsenic drinking water standard from 50 to 10 part per billion (ppb). Wisconsin's new SWCDA for this two-county area is designed to further protect human health and prevent aquifer degradation due to release of arsenic.

The Department established the new arsenic SWCDA for this entire area because:

- The main band of arsenic contamination runs diagonally all the way through this two-county area. Results of 25 Township-based sampling surveys done between 1999 & 2003 indicated 779 of 3,905 wells (19.9%) tested in these counties had arsenic levels exceeding 10 ppb.

- Arsenic is a primary drinking water contaminant that poses serious health concerns. It has been responsible for significant health problems throughout the world. Arsenic concentrations have not only shown increasing trends within this region, but have also increased dramatically in some individual wells.
- The Department's more stringent well construction, grouting and disinfection specifications have proven to be successful in providing water with low arsenic concentrations.



Distribution of private wells in Wisconsin with detects of arsenic

Over the past fifteen years DNR's understanding of the processes that deposited and formed arsenic-bearing minerals within the bedrock strata of Wisconsin has greatly improved. We have been able to map the geographic distribution of arsenic throughout much of the State.

Evidence suggests that in the geologic past sulfide compounds containing arsenic moved out of the Michigan Basin in the form of geothermal brines and precipitated out, in the form of sulfide minerals, into sedimentary bedrock aquifers of northeastern Wisconsin. These sulfide minerals became especially concentrated in a thin layer – the sulfide cement horizon (SCH) – at the top of the St. Peter Sandstone.

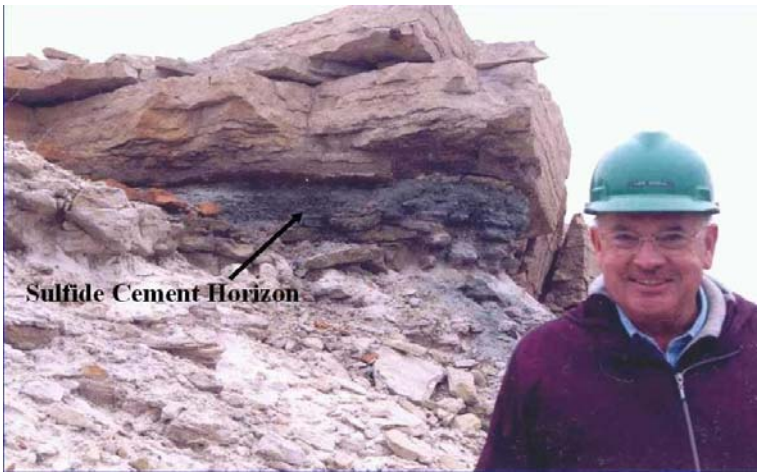


Photo A. The arsenic-laden sulfide cement horizon (SCH) within Skunk Hill Quarry northeast of Appleton, Wisconsin – Outagamie County. (Lee Smoll, Licensed Pump Installer and Well Inspector in foreground.)

Oxidation of sulfide minerals and associated release of arsenic appears to be primarily caused by the introduction of air into the aquifers. This seems to have happened due to a number of mechanisms including rotary-air drilling methods, fluctuating water levels within the bedrock formations and regional drawdown of water tables.

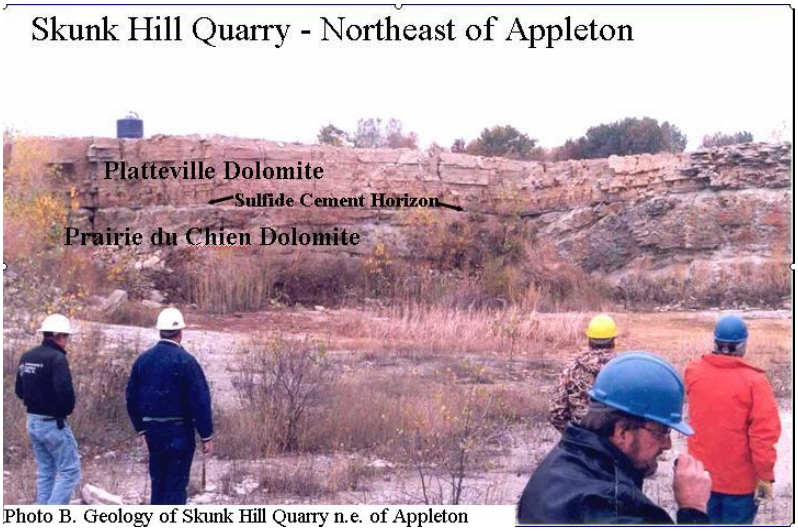


Photo B. Geology of Skunk Hill Quarry n.e. of Appleton

Photo B. Upper geologic layers of northeastern Wisconsin showing the position of the arsenic-bearing sulfide-cement horizon (SCH) within Skunk Hill Quarry, near Appleton. Person in foreground is noticing the garlic-type aroma characteristic of the arsenic-bearing sulfide minerals.

Initial attempts dealing with the arsenic problem

Identifying and understanding the arsenic problem of this region of Wisconsin has been one thing. Dealing with it has been quite another. We reported our initial attempts in a June, 2000 WWJ article. This article brings us up to date.

In 1993 much of the area of these two counties was included in a special well construction "Arsenic Advisory Area" (AAA) which remained in effect for 10 years.

There were, however, two major problems with the AAA. First, when the arsenic standard was lowered to 10 ppb we were faced with a much tougher objective. Secondly, because the deeper casing advisory of the AAA was only a recommendation, it was largely ignored.

We knew we not only had to come up with more stringent well specifications, we also had to make them requirements rather than mere recommendations. To do this we considered many aspects including regional geology, geographic & stratigraphic patterns of arsenic contamination, along with well construction, grouting & disinfection criteria. The more important specifications we decided on are:

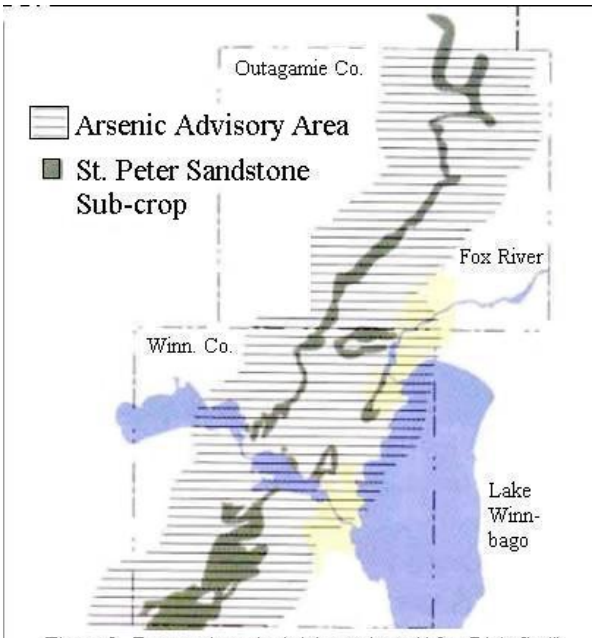


Figure 2 Former Arsenic Advisory Area (After Rick Stoll)

- *Rotary-air drilling methods*. To help prevent the oxidation of sulfide minerals, we decided to prohibit the use of rotary-air drilling methods and require rotary, mud-circulation methods for the construction of the upper-enlarged drillhole (UED). This greatly reduces the introduction of oxygen into the bedrock aquifers and helps prevents release of arsenic into groundwater.
- *More efficient grouting methods*. We specified the use of either the *Brandenhead* or *Grout-Shoe* method for cement grouting. Either of these two methods provides a strong impermeable grout envelope, uniformly surrounding the casing and adequately sealing it within the UED.
- *Modified disinfection procedures.* We limited the concentration and contact time of chlorine compounds for well disinfection. Concentrated batches can cause a release of arsenic on the wall of the lower open bedrock drillhole.
- *Use of desanders.* We required the use of a desander to help clean the hole of drill cuttings that can contain arsenic and to increase the chances for a better grouting job.

Because these stringent specifications worked satisfactorily for replacement wells funded by our Well Compensation program, we decided to apply them more extensively within this region.

Need for a comprehensive approach to the problem

Between 2002 and 2004 we applied the more stringent specifications within four small areas where arsenic contamination problems were severe. We subsequently realized that if we continued to establish SWCDAs in this manner, we would end up with a 'hodge-podge' of these small areas, scattered over this two-county region. We decided we needed a more comprehensive regional approach.

We knew we would have to include the worst areas of arsenic contamination. This necessitated greatly expanding the scope of SWCDA establishment process. We started by amassing all available existing and new well data, from both the DNR and Wisconsin

Geological & Natural History (WGNHS) databases. To do an accurate job of delineating and mapping the geology, we analyzed data from 6,000 wells within this two county area.

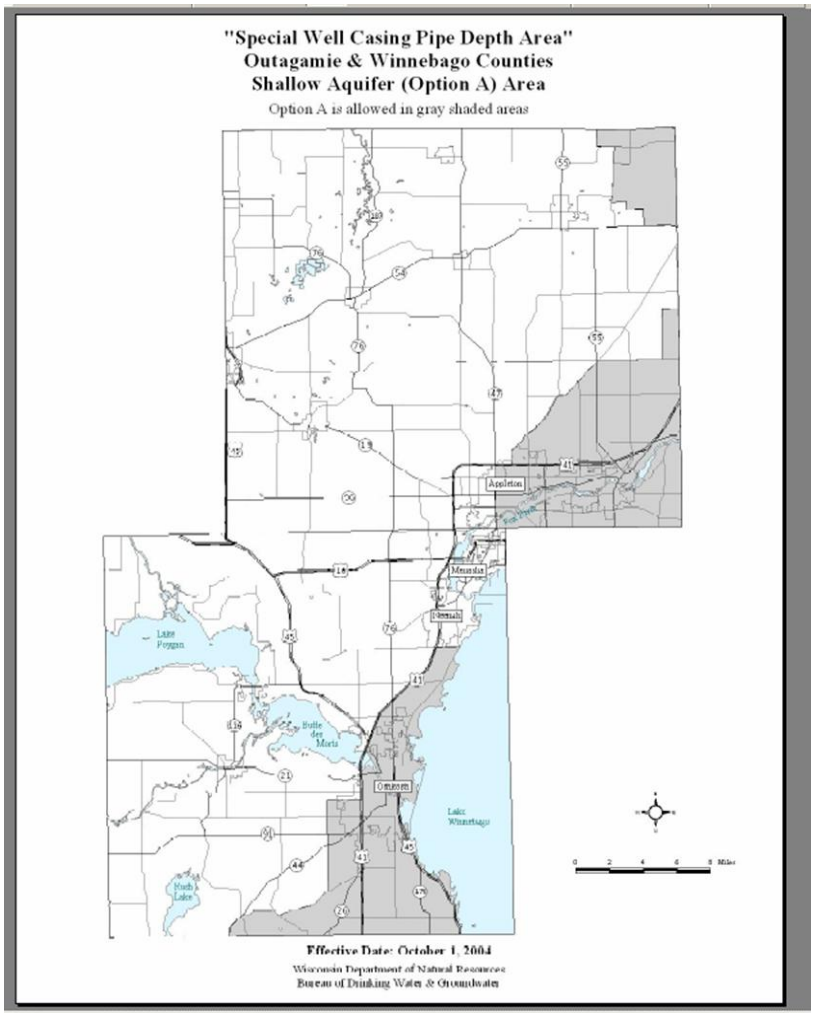


Figure 3. Newly established arsenic "Special Well Casing Depth Area" for Winnebago and Outagamie Counties. (Map by Amy Ihlenfeldt)

These well data points were entered into a computer software system which allowed us to generate a much more detailed geology map for this entire region. After much work and consideration we decided to establish a region-wide SWCDA to include all of Winnebago and Outagamie Counties.

Work on this project was coordinated between our department and the WGNHS. Earlier versions of the geology maps of these Counties were published decades ago and contained significant inaccuracies, especially across county boundaries. This work also resulted in some surprises with the geology:

- We knew the sequence of bedrock formations was not a simple 'layer-cake,' but we found it to be much more complicated than we had imagined. It includes several significant faults and some deep karst-type slump features.

- Intermittent sulfide deposits containing arsenic extend to significant depths below the SCH. They are not as concentrated in the SCH, but they are present, often in random

lenses. They extend through the St. Peter Sandstone and the underlying Prairie du Chien Dolomite, both of which overly the Cambrian Sandstone, the deepest arsenic-free aquifer.

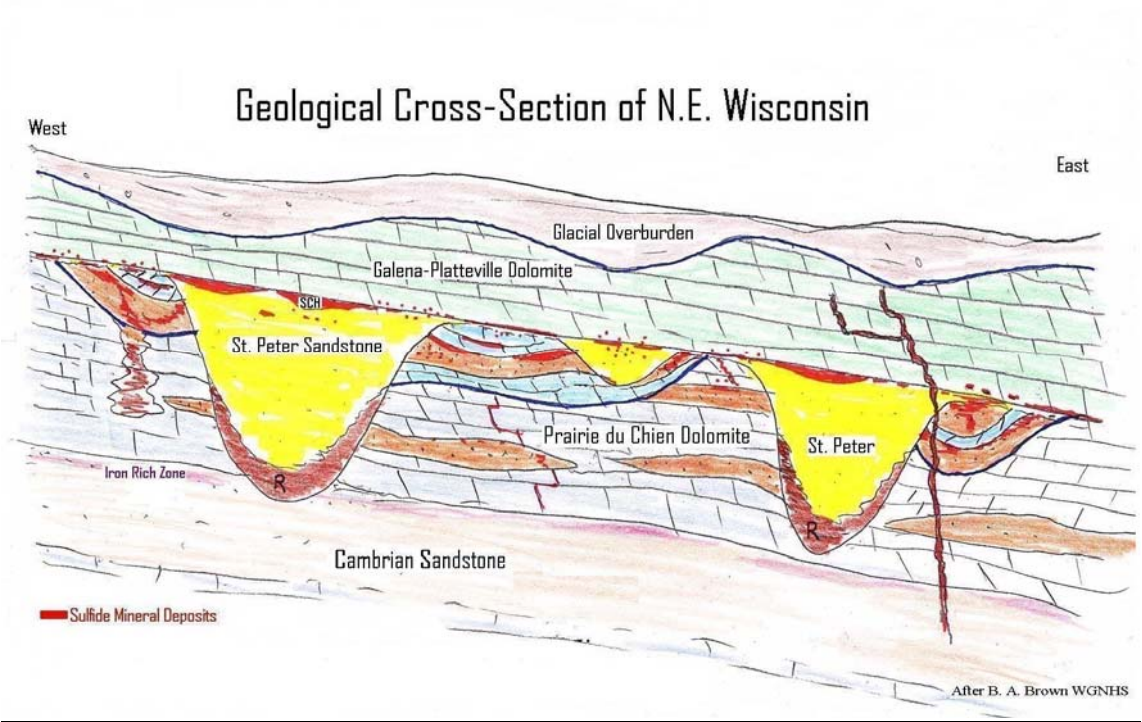


Figure 4. Upated geologic cross-section of arsenic area of northeastern Wisconsin

One of our main goals was to specify the construction of wells that would withdraw water from arsenic-free aquifers. To accomplish this we had to accurately map three important surfaces:

- *Ground topographic surface*. We used the best available digital elevation model to provide ground surface elevation control.
- *Top of the St. Peter Sandstone*. This surface not only represents the bottom of the shallow Galena-Platteville dolomite aquifer, but also the top of the arsenic-bearing SCH. The accurate delineation of this surface allowed us to generate maps that indicate where shallow Galena-Platteville dolomite wells are possible.
- *Top of the Cambrian Sandstone.* The Cambrian aquifer is made up of a thick sequence of sedimentary layers. The accurate delineation of the upper surface of this aquifer and its use in combination with the topographic surface allowed us to determine, at any location, the depth to this deep aquifer system.

Using these surfaces we were able to create detailed large-scale maps, one for each of the 35 townships within this two-county area. We supplied these maps to each Licensed Well Drilling firm in this area. The new specifications allow one of two well construction options:

- *Shallow Galena-Platteville Dolomite Aquifer Well* (Option A) This aquifer is present only in the southeastern portions of these counties, shown in gray on the map in Figure 3. An Option A well must be constructed to remain above the arsenic-laden

SCH. Within each quarter section on the maps – where a well in this aquifer is possible – a red number represents the depth to the bottom of the aquifer, minus a 20 foot 'buffer' to help ensure the SCH is not penetrated.

- *Deep Cambrian Sandstone Aquifer Well* (Option B) This aquifer is present throughout this two-county area, but can be very deep in the southeastern parts. On the township maps each quarter section is also provided with a black number that represents the approximate depth to the top of this aquifer. Regardless of what the number is, however, an Option B well must be cased and grouted at least into the Cambrian Sandstone. To help the drillers *find* the top of the Cambrian, we prepared a document that provides detailed descriptions of the geologic formations including their thicknesses, colors and other lithologic characteristics.

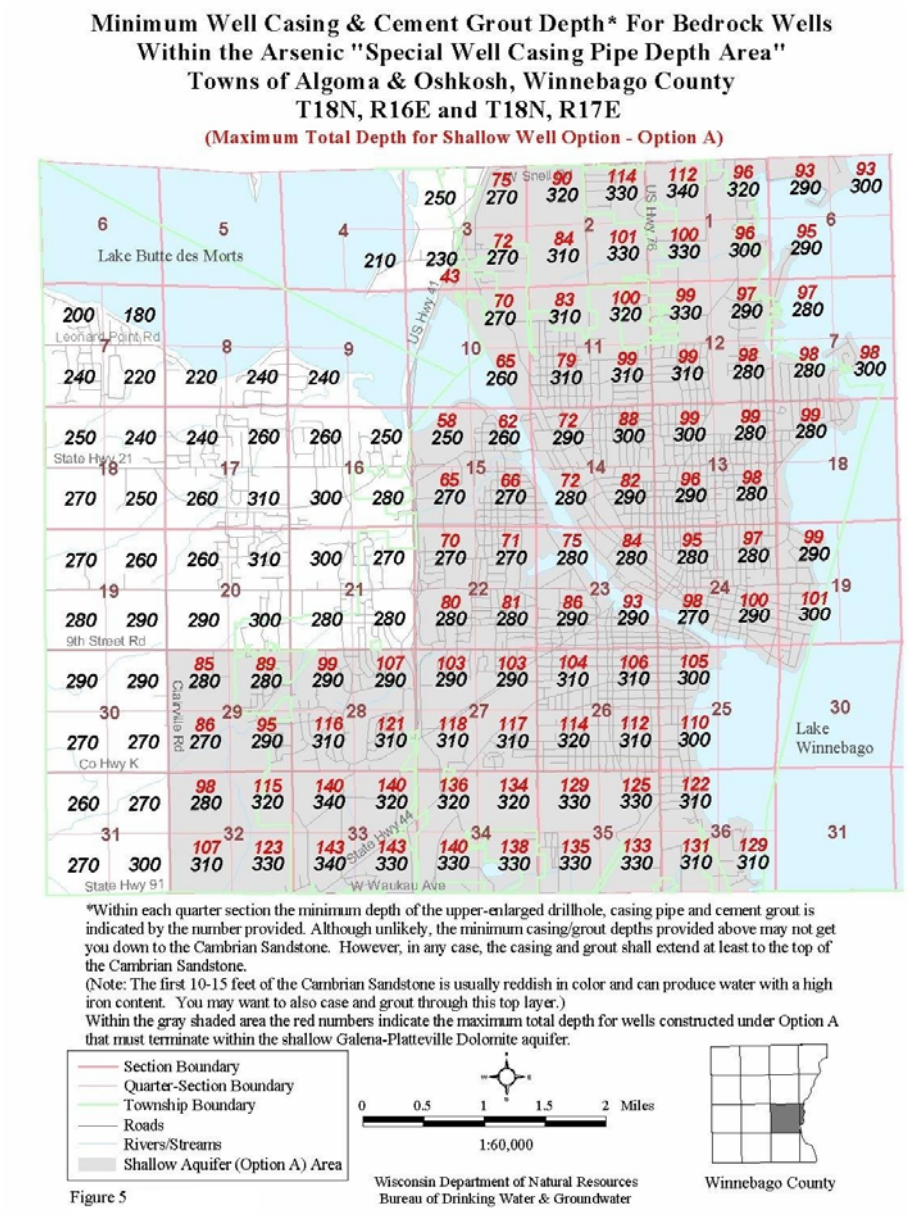


Figure 5. One of 35 Township maps indicating well construction options. (Map by Amy Ihlenfeldt)

Initial results of well construction, grouting and disinfection specifications

In order to determine how successful our stringent well construction specifications have been, we assembled the results of water samples collected from new wells and ran analyses on this data.

In the first year after the new specifications went into effect, 131 wells were constructed according to our more stringent specifications. Only eight of these (6 %) produced water with arsenic concentrations exceeding the new drinking water standard of 10 ppb. None of these had arsenic concentrations exceeding 50 ppb. (Owners of wells that produce water with arsenic levels greater than 50 ppb remain eligible for grants to help pay for a replacement well with a grant from out Well Compensation Program.)

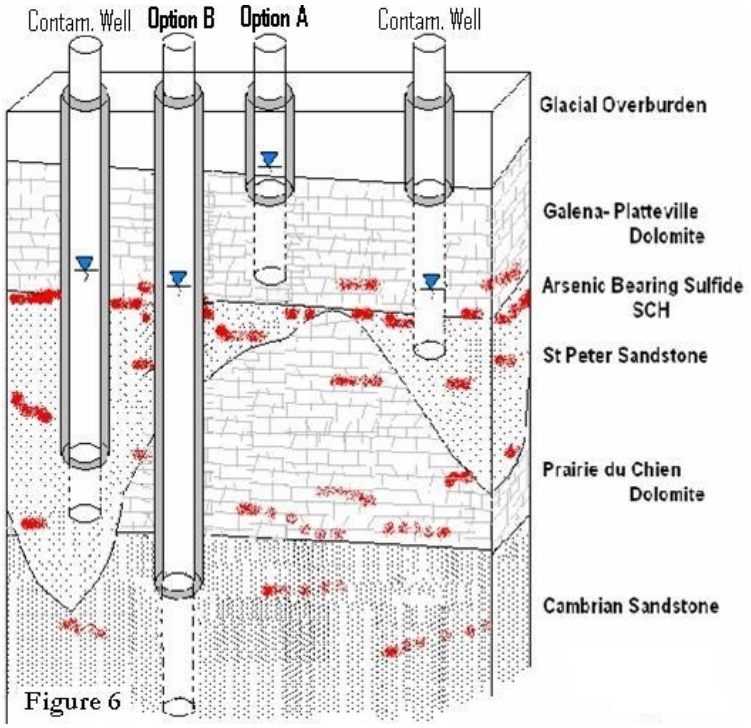


Figure 6. Allowable well construction options

The table below shows the percent of deeper wells that have had arsenic sample results exceeding 10 ppb and demonstrates the effectiveness of each of our more-stringent specifications.

Well Construction, Grouting or Disinfection Specification Used	**Percent of Wells with Arsenic > 10 ppb**
Short-cased well open to SCH **vs**. Well with casing set deep below SCH	55% **vs**. < 10%
Well drilled with Rotary-air **vs.** Rotary-mud and 'Rotary-Wash' methods	48% **vs**. 18%
Tremie pipe-pumped **vs**. *Bradenhead* or *Grout Shoe* method	61% **vs**. 7%
Dry (Ca) hypochlorite **vs**. Liquid (Na) hypochlorite disinfection product	40% **vs**. 19%
Heavy (> 300 ppm) chlorine **vs**. Light (< 100 ppm) disinfection solution	38% **vs**. 2%

Implementation of the provisions of this new regional SWCDA has gone rather well, but as with any new special construction requirements of this magnitude, well drillers have faced problems, including:

- Loss of drilling mud circulation within fractured formations
- *Finding* the top of the deep Cambrian Sandstone aquifer in some areas
- Removal of drill cuttings from the lower bedrock drillhole
- Significant loss of cement grout in some geologic situations
- Extra down-time waiting for grout to set
- Justifying the cost of wells in some areas where very deep casing settings are required

In first six months these requirements were in effect drillers expressed these concerns. To try to deal with these problems and concerns, we held an informational meeting in April of 2005. We explained reasons for and methods used in the Department's establishment of the arsenic SWCDA.

One concern emphasized by the drillers related to the difficulties they were having 'cleaning' cuttings out of the lower bedrock drillhole using the required *rotary-wash* drilling method. They asked if we would consider allowing the use of some form of air-lift methods to develop these wells.

We subsequently decided to allow the use of air-lift development methods to help clean and develop the open bedrock drillhole, but only if the air is injected up inside the well casing. We also placed restrictions on the pressure and volume of the injected air to help prevent it from oxidizing arsenic-bearing minerals. By creating an 'updraft' of compressed air within the casing, drillers have found they can more efficiently remove cuttings and debris the bedrock drillhole.

We are currently engaged in an update of the mapping of the bedrock surfaces with the use of more powerful computer software along with newly submitted well construction reports, many of which extend to much greater depths. This effort will further refine our understanding of the geologic complexities of this area so we can provide, more accurate maps to the drillers.

The completion of this project would not have been possible without the able and generous assistance of the folks at the WGNHS and the funding provided by the USGS State Mapping program. We greatly appreciate their work and assistance.

April, 2006

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